NUMERICAL INVESTIGATION ON THE EFFECT OF DIFFERENT STRUT ANGLE TO THE CEREBRAL ANEURYSM

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We certify that the project entitled "*Numerical Investigation on the Effect of Different Strut Angle to the Cerebral Aneurysm*" is written by *Noor Harliana bt A. Hamid.* We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering. We herewith recommend that it is accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

Mr Muhamad Zuhairi Sulaiman

Examiner Signature

To

My parents and my family

A.Hamid bin Taha

Nashihah binti Idris

Nashrul Harzumy bin A.Hamid

Noor Hartiny binti A.Hamid

Noor Haryanty binti A.Hamid

for their tireless sacrifice, love and cheerful encouragement.

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project report and in our opinion this project is satisfactory in terms of scopes and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature	:
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Position	: Lecturer
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STUDENT'S DECLARATION

I hereby declare that the work in this report is my own except for quotations and summaries which have been duly acknowledge. The report has not been accepted for any degree and is not concurently submitted for award of other degree.

Signature :
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ABSTRACT

The objective of this study was to determine the correlation of stent strut angle to blood flow and also to determine the flow behavior in stented aneurysm. The computational fluid dynamics was applied to access the changes of velocity and pressure in aneurysms. For this study, there are five stent with the same design but different in strut angle of the stent. The strut angle used in this study was 30°, 35°, 35°, 40°, 45° and 50°. By using 30° of strut angle as the control model and the other angle as the experimental model, there are referred to as type I, type II, type III and type IV. The simulation of the model was studied under incompressible, Newtonian, viscous and non-pulsatile condition. The results for all stents analyzed in the current study showed that the stent with higher angle are more efficient than stent with lower angle. The minimum velocity increased with the implacement of stent type IV which is the higher strut angle. Meanwhile, for the pressure distribution of all type of stents indicate that lowest peak pressure obtained by stent type III. Therefore, strut angle used should be suitable to satisfy the requirement of lowest peak pressure and highest minimum velocity. So, the strut angle has to be maintained within a certain range, which varies from 40° to 45°. Finally, the correlation obtained from this numerical result could be used to investigate the pressure distribution around the aneurysms.

ABSTRAK

Objektif kajian ini adalah untuk menentukan perhubungan sudut di antara stent terhadap aliran darah dan juga untuk menentukan aliran darah . Program dinamik bendalir tiga dimensi telah digunakan untuk mengakses perubahan halaju dan tekanan dalam aneurism. Untuk kajian ini, terdapat lima stent yang mempunyai rekabentuk sama tetapi berbeza sudut di antara stent. Sudut yang digunakan dalam kajian ini adalah 30°, 35°, 35°, 40°, 45° dan 50°. Dengan menggunakan sudut 30° sebagai model kawalan dengan yang selebihnya sebagai model eksperimen, ianya dirujuk sebagai stent jenis I, jenis II, jenis III dan jenis IV. Simulasi model dikaji dengan parameter aliran mampat, Newtonian, bendalir likat dan keadaan tiada denyut. Keputusan untuk semua stent yang dianalisis menunjukkan stent yang mempunyai sudut yang lebih besar adalah lebih efisien berbanding stent yang bersudut kecil. Halaju minimum ditingkatkan dengan implant stent jenis IV di mana ianya stent yang bersudut paling besar. Walau bagaimanapun, taburan tekanan untuk semua stent menunjukkan tekanan puncak terendah dihasilkan oleh stent jenis III. Oleh itu, sudut di antara stent harus sesuai untuk memenuhi kehendak tekanan puncak terendah dan halaju minimum tertinggi. Justeru, sudut di antara stent harus dikekalkan dalam satu julat iaitu dari 40° hingga 50°. Perkaitan diperolehi dari kajian ini boleh dimanfaatkan untuk lanjutan taburan tekanan disekitar aneurism.

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u_i	velocity in the *i*-th direction
P	pressure
f_i	body force
ρ	density
μ_i	viscosity
δ_{ij}	Kronocker delta

LIST OF ABBREVIATIONS

3DRA	Three-dimensional rotational angiography
CFD	Computational Fluid Dynamics
CT	Computer-assisted tomographic
DSA	Medical substraction angiography
FEFLO	Incompressible flow solver
GTA	Computer tomographic angiography
ICA	Intracranial aneurysm
ISR	In-stent restenosis
LBM	Lattice-Boltzmann Method
LDV	Laser-Doppler velocimetry
MRA	Magnetic resonance angiography
MRI	Magnetic resonance Imaging
PIV	Particle-image velocimetry
PTFE	Polytetrafluoroethylene
PTV	Particle-tracking velocimetry
SPH	Smooth-particle hydrodynamics
WSS	Wall shear stress

CHAPTER 1

INTRODUCTION

1.1 BRAIN ATTACK

A “brain attack” is the brain version of heart attack and it occurs when blood circulation to the brain fails. Brain cells can die from decreased blood flow and the resulting lack of oxygen. There are two broad categories of stroke: those cause by a blockage of blood flow and those caused by bleeding. The most frequent cause of loss of blood supply to brain tissue is atherosclerosis. However, blood supply may be lost due to another important reason: a ruptured blood vessel. When a brain aneurysm ruptures, the blood flowing in the parent artery from which the aneurysm arose is suddenly no longer flowing to the nerves and other cells that make up normal brain tissue; in effect, this blood now gushes out into the subarachnoid space. The region of brain which has once supplied by that parent artery whose aneurysm has now burst become ischemic, and may thereafter become infracted.

1.1.1 Structure of the brain arteries

Brain arteries can be likened to steel cylindrical pipes, each consisting of a wall enclosing a hollow space. The larger brain arteries run in a space on the surface of the brain known as the subarachnoid space.

The wall of a brain artery is comprised of three major layers and the total of six main components. The three main layers of an artery are the intima, the media and the adventitia. Between the media and the intima is a thin layer of elastic tissue. This layer is referred to as the elastic lamina, and it is the only elastic layer occurring in the wall of the brain artery. The elastic layer has many naturally occurring openings (perforations) in it.

The six components of a blood vessel wall are endothelial cells, collagen fibers, elastic fibers, smooth muscle cells, fibroblasts and nerve fibers. In the smallest of the brain vessels, known as brain capillaries, there are also two other cell type, namely, astrocytes and pericytes .

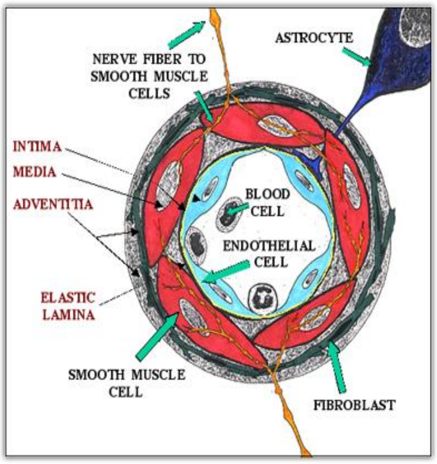


Figure 1.1: Structure of normal brain artery

Source: www.brainaneurysm.com

1.1.2 The organization of brain arteries

Brain arteries are organized as follows: from the main pipes that enter into the brain, a ring from the arteries arises that encircles the under surface of the brain. This ring is known as 'Circle of Willis'.

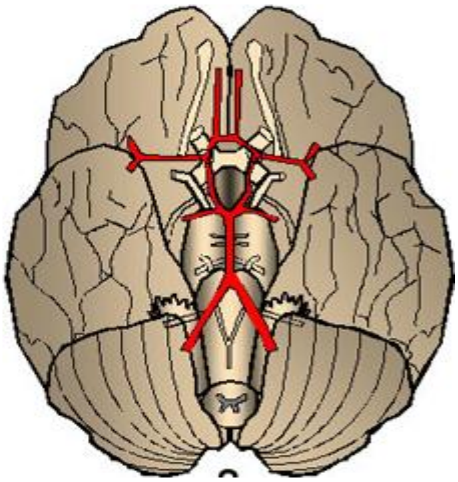


Figure 1.2: Circle of Willis

Source: www.brainaneurysm.com

Figure shows the under-surface of the brain. The major arteries in this region are shown in red. Together they have formed a ring-like structure called the ‘Circle of Willis’, a critical point of communication between the main arteries supplying the substance of the brain. The front part of this group of arteries is referred to as the ’anterior circulation’; the back part is referred to as the ‘posterior circulation’. All of these arteries lie in the ‘subarachnoid space’ (SAS), a space normally filled with circulating cerebrospinal fluid.

1.2 ANEURYSM

The most common pathology that usually found in human arteries and some primates is the aneurysm. The intracranial aneurysm is generally found in females than in males. [1] These intracranial aneurysms mostly not rupture if their diameter is less than 10mm. But for cerebral aneurysms, if their size is roughly larger than 5 mm in diameter, it is considered as a critical. The rupture of an intracranial aneurysm will resulting subarachnoid hemorrhage that is serious events and it associated with high rates of mortality and morbidity. [1]

There are some types of aneurysms that can occur in the body. There are about four different types of aneurysm which is thoracic aortic aneurysm, abdominal aortic aneurysm, cerebral aneurysm and peripheral aneurysm. It can be simplified in Table 1.

It should be noted that there are different several types of cerebral aneurysm. They are being classified through the involving layers of the wall. There are two most recognized shapes of aneurysms which is ‘saccular’ and ‘fusiform’. The third shape,’mycotic’ are also recognized but it is much rarer than the other two. These three shapes of aneurysms is an expansion of a blood vessel wall involving all layers of the wall. It can be shown in Table 2.

The role of genetic factors will lead to the intracranial aneurysms, but other factors, such ads hemodynamic stress at arterial bifurcations, congenital medical defects, degenerative artery wall changes, smooth muscle cell apoptosis, smoking and excessive alcohol consumption are also the factors that contributed to aneurysmal development.[1] The changes of the aneurysmal wall are already advanced or have been modified with other factors once it is detected. Therefore, it will known the details on how they originate, grow and rupture.

Cerebral arteries are muscular arteries that having significantly less elastin in the media (than elastic arteries) and lacking the external elastic lamina. Most bifurcations of the cerebral vasculature are structurally stable, but a small number develop a weakness that causes the wall to expand outwardly in the region near the flow divider of the branching artery.

Table 1.1: Types of aneurysm

(Source: http://www.nhlbi.nih.gov, http://www.mayoclinic.org)

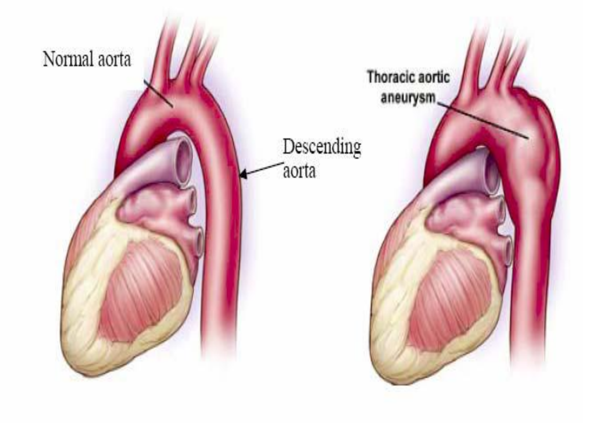
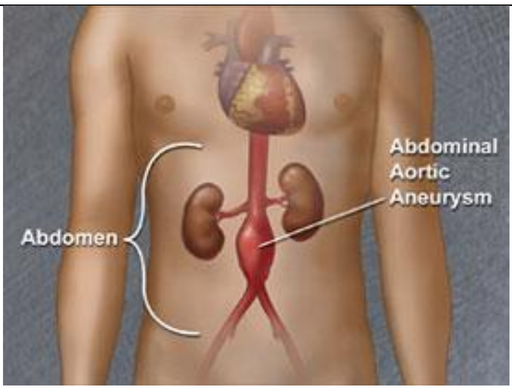
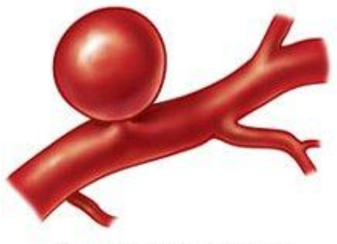
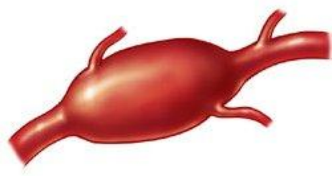
Types of aneurysm	Figure
Thoracic Aortic	
Abdominal Aortic	
Cerebral	

Table 1.2: General shape of aneurysm

(Source: http://www.discuss.com.hk)

No	Shape of Aneurysm	Figure
1	Saccular	
2	Fusiform	

Hemodynamic stress at certain points of the arterial tree might be an important factor in both triggering aneurysm growth and leading to rupture of an existing aneurysm. Medical imaging technique, such as medical subtraction angiography (DSA), computer tomographic angiography (GTA) or magnetic resonance angiography (MRA) are now capable of providing more accurate three-dimensional information on intracranial vessel geometry.[4]

The gold standard for detection of a brain aneurysm is cerebral angiography. Here, a contrast dye is first injected through a catheter device inserted usually in a thigh (femoral) artery. From here, the dye is eventually enters one or more of the main brain arteries, where it is X-ray imaged. It typically provides a detailed roadmap of the brain circulation. An aneurysm appears as an expansion of the vessel. If there is no clot (thrombus) in the aneurysm, it will light up like a sac coming off the parent artery. If the lumen (or inner space) of the brain aneurysm is packed with clot (this is more common in bigger brain aneurysm due to slowing of blood flow in the lumen), then sometimes the real extent of the brain aneurysm is may not seen by this method.

Other X-ray based advanced imaging methods for detecting brain aneurysm are magnetic resonance imaging (MRI) and its associated method referred to as magnetic resonance angiography (MRA). The advantages of these method are that they are less invasive than cerebral angiography, in that they do not involve femoral (thigh) artery puncture and insertion and navigation of a long catheter through the arteries. However, they may not detect the smallest of brain aneurysm as well as cerebral angiography can, and are not able to be used in certain patient in whom metallic hardware has been placed.

Ordinary computer-assisted tomographic (CAT or CT) scanning with a limited injection of contrast dye is another way to detect brain aneurysm, but not a very good way (note that without injection of contrast, an ordinary CT scan is almost useless unless the brain aneurysm is very large, calcified and ruptured).Even when used as part of CT angiography, this method is not as sensitive or as specific compared with cerebral angiography.

If a brain aneurysm is detected, but hasn't ruptured, the choice of treatments is very controversial at the moment. Some physicians have found that a brain aneurysm diameter (size) of 10mm may be the critical number after there is a significantly increased risk of brain aneurysm rupture. Other, however, have found that rupture occurs in even smaller brain aneurysms (3 to 6mm in diameter) and therefore advocate that the 10mm size 'threshold' is not valid for determining risks and deciding on close observation versus actual treatment. The bottom line is that each case of brain aneurysm should be treated on an individualized basis, taking into the consideration the age of the patient, copresence of significant medical conditions, the site and size and shape of the brain aneurysm, whether there is a history of previous aneurismal hemorrhage in the patient, the experience of the treating physician and surgeon, and the type and risk(s) of treatment option most suitable for that brain aneurysm and person. There are some techniques for treating a brain aneurysm as shown in Figure 1.7. Firstly shows a directly clipped accross brain aneurysm neck, thereby effectively removing the brain aneurysm from the circulation. Second figure shows a trapping of a brain aneurysm, with surgical clips being placed on the artery sections and draining brain aneurysm. Last figure shows a hollow stent (S) being placed by catheter across the region of the vessel that opens into the lumen of the brain aneurysm.

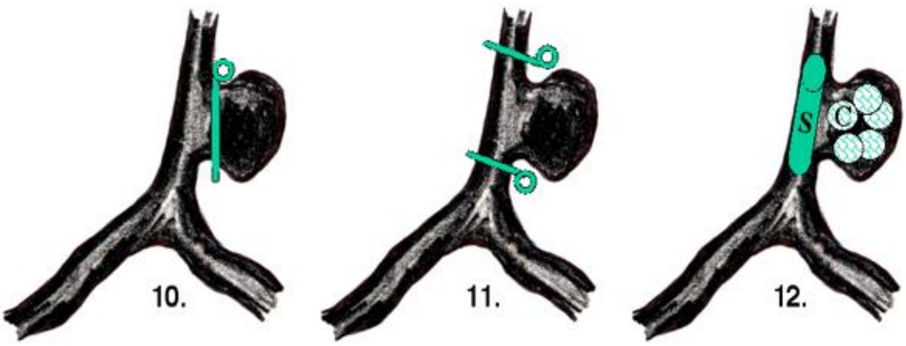


Figure 1.3 Techniques for treating brain aneurysm

Source: www.brainaneurysm.com

1.3 STENT

At present, the market of stent is increasing rapidly as a method of reopening the clogged blood vessels of the legs and heart. It is because of their high initial success rate, minimal invasive nature and improved long-term effectiveness than the other method. There are three most common treatment for vascular disease which does not respond to pharmacologic therapy are vascular bypass grafting, percutaneous transluminal balloon angioplasty and percutaneous transluminal stenting with the aid of balloon angioplasty.[2]

At the turn of the 20th century, one of the scientific breakthroughs is the introduction of the drug-eluting stent, also known as drug-coated stent. With the technological advancement in engineering and design, drug-coated stent has become as ultimate device in treating cardial vascular disease. As a result, others stent parameters are taken lightly and considered less important by many specialists. The under appreciation of the stent design, that has evolved for the pass 18 years, will affect the overall performance of the stent. The structural, geometry and dimension play a crucial role in the delivery process, performances of the stent and the procedural success.

The stent was introduced to replace the tradition invasive surgery and angioplasty balloon that was use in treating cardial vascular disease. In early stage of angioplasty, cardiologists use balloon to expand the artery that is clogged. However, in some cases the wall of the coronary artery become weakened after the balloon is dilated, resulting an acute or sub acute collapse of the artery. The stent was created in 1980s in response to the danger posed by the angioplasty balloon. The stent was able diminish the danger of collapsing artery wall, but it gave birth to the problem of restenosis. After years of engineering and design, the stent is equipped with biocompatible and radio visible coating with reduce restenosis. The coating on stent is not only the factor that is responsible for today stent performance and success in procedures, but many other stent parameters.

Stent that is inserted into a vascular which it features either an expandable wire or perforated tube is to avoid a disease-induced localized blood flow constriction.[2] This technique is viewed as a minimally invasive treatment and a very promising alternative or complement to more traditional approaches such as coils and surgery. [4] However, the optimal design for the stent structure is depend on the specific location and type of aneurysm. Issues with respect to the design of vascular stents include maximal radial stiffness, maximal flexibility, minimal foreshortening, minimal dogboning, minimal longitudinal recoil, minimal coverage area, maximal fatigue durability.

Particularly, foreshortening driven from unfavorable shearing between the stent and the vascular or dogboning induced from penetration at the edges of the stent, can be primary cause of potential limitations such as restenosis. Thus, new stent design should focus on features related to mechanical performances while considering the other issues described above to mechanical characteristics.[4]